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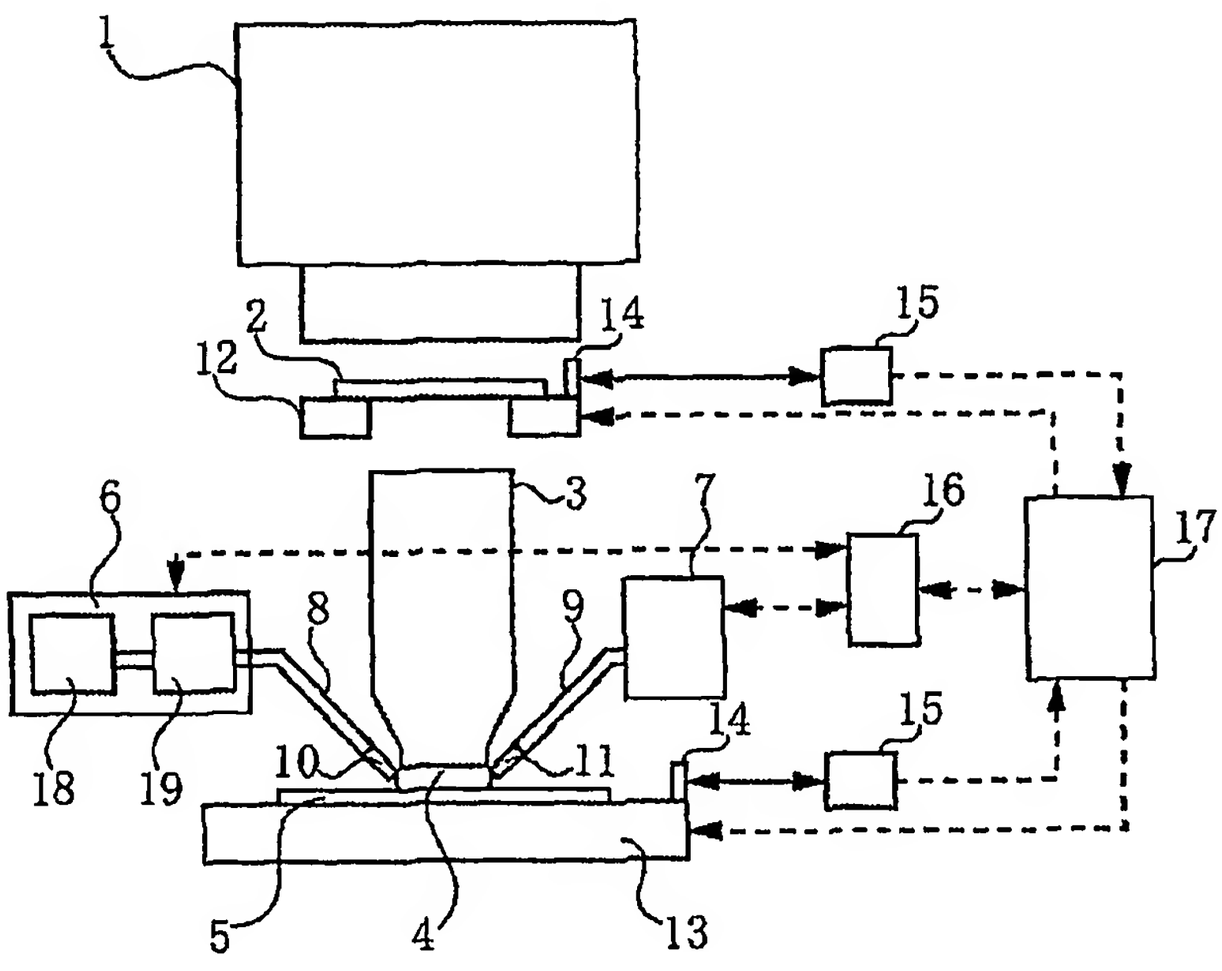
(54) Title: EXPOSURE APPARATUS AND DEVICE MANUFACTURING METHOD

(57) Abstract: An exposure apparatus includes a projection optical system (3) for projecting a pattern of a mask (2) onto a substrate (5), and a fluid supply unit (6) for supplying a fluid between said projection optical system and the substrate, said fluid supply unit (6) including an injection unit (19) for injecting carbon dioxide into the fluid.



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DESCRIPTION

EXPOSURE APPARATUS AND DEVICE MANUFACTURING METHOD

TECHNICAL FIELD

This invention relates generally to an exposure apparatus that utilizes an immersion method, and is suitable, for example, for the lithography process for manufacturing highly integrated devices, such as semiconductor devices, *e.g.*, ICs and LSIs, image pick-up devices, *e.g.*, CCDs, display devices, *e.g.*, a liquid crystal panels, communication devices, e.g., optical waveguides, and magnetic heads by transferring a pattern of a mask (or a reticle) onto a photosensitive agent applied substrate.

BACKGROUND ART

An exposure apparatus for exposing a mask pattern onto a photosensitive-agent applied substrate have conventionally been used to manufacture semiconductor devices and liquid crystal panels. Since finer processing of a pattern is demanded for improved integrations of devices, exposure apparatuses are improved so as to resolve fine patterns.

The following Rayleigh equation (1) defines resolution R of a projection optical system in an exposure apparatus, which is an index of a size of a resolvable pattern:

$$R = k_1 (\lambda / NA) \quad (1)$$

where λ is an exposure wavelength, NA is a numerical aperture of the projection optical system at its image side, and k_1 is a constant determined by a development process and others, which usually is approximately 0.5.

As understood from Equation (1), the resolving power of the optical system in the exposure apparatus becomes higher as the exposure wavelength is shorter and the image-side NA of the projection optical system is greater.

Therefore, following the mercury lamp i-line (with approximately 365 nm in wavelength), a KrF excimer laser (with approximately 248 nm in wavelength) and an ArF excimer laser (with approximately 193 nm in wavelength) have been developed, and more recently an F_2 excimer laser (with approximately 157 nm in wavelength) is reduced to practice. However, a selection of the exposure light having a shorter wavelength makes it difficult to meet material requirements with respect to transmittance, uniformity and durability, etc., causing an increasing cost of the apparatus.

An exposure apparatus having a projection optical system with a NA of 0.85 is commercially available, and a projection optical system with a NA of 0.9 or greater is researched and developed. Such a high-NA exposure apparatus has difficulties in maintaining good imaging performance with little aberration over a large area, and thus utilizes a scanning exposure system that synchronizes the mask with a substrate during exposure.

However, a conventional design cannot make the NA greater than 1 in principle due to a gas layer having a refractive index of about 1 between the projection optical system and the substrate.

On the other hand, an immersion method is proposed as means for improving the resolving power by equivalently shortening the exposure wavelength. It is a method used for the projection exposure, which fills liquid in a space between the final surface of the projection optical system and the substrate, instead of filling this space with air as in the prior art. The projection exposure apparatus uses, as the immersion method, a method for immersing the final surface of the projection optical system and the entire substrate in the liquid tank (see, for example, Japanese Patent Application, Publication No. 6-124873), and a local fill method that flows the fluid only in the space between the projection optical system and the substrate

(see, for example, International Publication No. WO99/49504 pamphlet).

The immersion method has an advantage in that the equivalent exposure wavelength has a wavelength of a light source times 1 / n, where n is a refractive index of the used liquid. This means that the resolving power enhances by 1 / n times the conventional resolving power, even when the light source having the same wavelength is used.

For example, when the light source has a wavelength of 193 nm and the fluid is the water, the refractive index is about 1.44. Therefore, use of the immersion method can improve the resolving power by 1 / 1.44 times the conventional method.

The most common fluid used for the immersion method is water. The water has a good transmittance relative to the ultraviolet light down to about 190 nm. In addition, advantageously, a large amount of water is used in the semiconductor manufacturing process, and the water gets along with the wafer and photosensitive agent.

It is important to reduce the influence of the air gas bubbles to the exposure in the immersion exposure apparatus. These gas bubbles that enter the exposure area between the final surface of the projection optical system and the substrate scatter the exposure light. Therefore, the transferred pattern's critical

dimension varies beyond the permissible range, causing insulations and short circuits contrary to the design intent in the worst case. Degassing of the fluid is the most effective, known method to prevent the influence of the gas bubbles to the exposure. Since the gas bubbles are unlikely to occur or the generated gas bubbles extinguish in a short time period in the degassed fluid, the influence of the gas bubbles to the exposure is prevented.

However, the water widely used for the immersion method increases the resistivity, when degassed, and is likely to generate static electricity disadvantageously. For example, the pure water (*i.e.*, the water containing few impurities) used for the semiconductor manufacturing process reaches the resistivity of 18 MΩ·cm after degas. The substrate surface is electrically insulated since the photosensitive agent is applied on it. Therefore, as the stage moves the substrate, the static electricity is generated on the substrate surface and makes the device on the substrate defective.

DISCLOSURE OF INVENTION

With the foregoing in mind, the present invention has an exemplary object to provide an exposure

apparatus that uses an immersion method while reducing the static electricity on the substrate.

An exposure apparatus according to one aspect of the present invention includes a projection optical system for projecting a pattern of a mask onto a substrate, and a fluid supply unit for supplying a fluid between the projection optical system and the substrate, the fluid supply unit including an injection unit for injecting carbon dioxide into the fluid.

An exposure apparatus according to another aspect of the present invention includes an illumination optical system for illuminating a mask using light from a light source, and a projection optical system for projecting a pattern of the mask onto a substrate, wherein a fluid supplied to a space between the projection optical system and the substrate has a concentration of carbon dioxide between 0.02 ppm and 750 ppm.

An exposure apparatus according to still another aspect of the present invention includes an illumination optical system for illuminating a mask using light from a light source, and a projection optical system for projecting a pattern of the mask onto a substrate, wherein a fluid supplied to a space between the projection optical system and the substrate has a resistivity value between 0.02 MΩ·cm and 10 MΩ·cm.

A device manufacturing method according to another aspect of the present invention includes the steps of exposing an object using the above exposure apparatus, and developing the exposed object.

Other objects and further features of the present invention will become readily apparent from the following description of the embodiments with reference to accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

FIG. 1 is a schematic view of a principal part in an exposure apparatus of a first embodiment.

FIG. 2 is a schematic view showing a structural example of an injection unit of carbon dioxide.

FIG. 3 is an explanatory view showing a relationship between a potential on a wafer and a pure water's resistivity in a wafer's cleansing step.

FIG. 4 is an explanatory view showing a relationship between the pure water's resistivity and the concentration of carbon dioxide.

FIG. 5 is an explanatory view showing a relationship between a normalized life of a gas bubble and a normalized concentration of a dissolved gas.

FIG. 6 is an explanatory view showing a relationship between a water's PH value and a concentration of the carbon dioxide.

FIG. 7 is a schematic view showing a principal part of an exposure apparatus as a variation of the first embodiment.

FIG. 8 is a manufacture flow of a device.

FIG. 9 is a wafer process shown in FIG. 8.

BEST MODE FOR CARRYING OUT THE INVENTION

Preferred embodiments of the present invention will now be described in detail in accordance with the accompanying drawings.

FIRST EMBODIMENT

FIG. 1 is a schematic view of a principal part of an exposure according to a first embodiment. This embodiment applies the present invention to a scanning exposure apparatus.

In FIG. 1, 1 denotes an illumination optical system for illuminating a reticle (or a mask) with light from a light source. The light source is an ArF excimer laser (with a wavelength of 193 nm), a KrF

excimer laser (with a wavelength of 248 nm), and F_2 laser, and the illumination optical system 1 includes a known optical system etc. (not shown). 3 denotes a refracting or catadioptric or another projection optical system for projecting a circuit pattern of a reticle 2 illuminated by the illumination optical system 1, onto a wafer 5 (substrate) as a second object. 15 denotes a distance measuring laser interferometer for measuring a two-dimensional position on a horizontal plane of each of a reticle stage 12 and a wafer stage 13 via a reference mirror 14. A stage controller 17 controls positioning and synchronizations of the reticle 2 and the wafer 5 based on this measurement value. The wafer stage 13 serves to adjust a position in a longitudinal direction, a rotational angle, and an inclination of a wafer so that the surface of the wafer 5 matches the image surface of the projection optical system 3.

This embodiment uses the immersion method to shorten the equivalent exposure wavelength, and improve the exposure resolution. Therefore, this embodiment arranges a supply port 10 and a recovery port 11 around the final surface of the projection optical system 3, supply the water between the final surface of the projection optical system 3 and the wafer 5, and form a liquid film 4 there. An interval between the final surface of the projection optical system 3 and the

wafer 5 is preferably small enough to stably form the liquid film 4, such as 0.5 mm. The supply port 10 is connected via a supply tube 8 to a fluid supply unit 6 that supplies the water. The recovery port 11 is connected via a recovery tube 9 to a fluid recovery unit 7 that recovers the water. The fluid supply unit 6 includes a degassing unit 18 and a carbon dioxide injection unit 19 provided at the downstream of the degassing unit 18. The degassing unit 18 can have, for example, a well-known membrane module (not shown) and a vacuum pump (not shown). An immersion controller 16 sends a control signal to the fluid supply unit 6 and the fluid recovery unit 7, and transmits and receives data with a stage controller 17. Thereby, the immersion controller 16 adjusts the liquid supply amount and recovery amount according to the wafer's moving direction and speed.

This embodiment injects a predetermined concentration of carbon dioxide into the degassed water, prevents influence of gas bubbles to the exposure, and restrains the static electricity on the substrate. Carbon dioxide advantageously is inexpensive and does not contaminate the substrate. Referring to FIG. 2, a description will be given of one exemplary structure of the carbon dioxide injection unit 19. A membrane module 22 is provided between an inflow port 20 of the water and an outflow port 21. The membrane module 22

is connected to a supply source 24, such as a CO_2 cylinder, via a valve 23. The valve 23 is electrically controlled by a carbon dioxide controller 25.

This configuration restrains a concentration of the carbon dioxide in the water by changing the flow of the carbon dioxide to the membrane module 22 via the valve 23. A resistivity meter 26 is provided at a downstream side of the carbon dioxide injection unit. It is more preferable to control the concentration of the carbon dioxide within a predetermined range by electrically feeding back an output of the resistivity meter 26 to the carbon dioxide controller 25. Carbon dioxide gas may be injected into the water from a nozzle instead of using a membrane module. In this case, it is preferable to eliminate fine particles in the carbon dioxide gas using a filter in advance.

A description will now be given of an optimal concentration of carbon dioxide.

The lower limit of the carbon-dioxide concentration is determined from the necessity to restrain the static electricity on the wafer. FIG. 3 shows a relationship between the potential on the wafer and the water's resistivity when the wafer is cleansed with pure water from the nozzle (as detailed in Asano, "Spray, Contact, Flow Charges of Pure Water and Ultra-pure Water", The Institute of Electrical Engineering of Japan, Vol. 108 (1988), pp. 362-366). It is understood

from FIG. 3 that when the water's resistivity exceeds 10 MΩ·cm, the large potential is likely to generate on the wafer. On the other hand, when the water's resistivity is equal to or smaller than 5 MΩ·cm, the static electricity does not pose a problem. FIG. 4 shows a relationship between the carbon-dioxide concentration and the resistivity in the pure water. As the carbon-dioxide concentration increases, the resistivity decreases. The carbon-dioxide concentrations of 0.02 ppm and 0.06 ppm correspond to the resistivity of 10 MΩ·cm and 5 MΩ·cm. This means that the carbon-dioxide concentration in the water is preferably 0.02 ppm or greater, more preferably 0.06 ppm or greater, in order to restrain the static electricity on the wafer.

The upper limit of the carbon-dioxide concentration can be determined from a problem of the gas bubbles. The gas-bubble generation is caused by a pressure variance in the water and inclusions of fine gas bubbles in the carbon-dioxide injection unit. In either case, as the carbon-dioxide concentration in the water increases, the gas bubble is likely to generate and its life (or a time period during which a generated gas bubble extinguishes due to diffusion) becomes long. In other words, the gas bubble is unlikely to extinguish and a danger of the influence of the gas bubbles to the exposure increases. FIG. 5 shows the

normalized life τ / τ_0 of a gas bubble as a function of C_s / C_∞ as a normalized concentration of dissolved gas (as detailed in C. E. Brennen, "Cavitation and Bubble Dynamics, "Oxford University Press (1995), Chapter 2). Here, τ_0 is the life when C_∞ = 0.0 and Cs is a saturated concentration. When normalized concentration C_s / C_∞ is 0.2 or smaller, the life of a gas bubble is close to C_∞ = 0.0 and the gas bubble is likely to extinguish relatively immediately. On the other hand, when normalized concentration C_s/C_∞ becomes 0.5 or greater, the life of a gas bubble drastically increases and gas bubble is unlikely to extinguish. As a result of this, in order to prevent the influence of the gas bubble to the exposure, the concentration of gas dissolved in the water is preferably 50 % or smaller of the saturated concentration, and more preferably 20 % or smaller of the saturated concentration. The saturated concentration of carbon dioxide in the water is about 1500 ppm in one air pressure. Therefore, in order to prevent the influence of the gas bubbles to the exposure, the carbon-dioxide concentration may be preferably 750 ppm or smaller, more preferably 300 ppm. These values are much greater than the lower limit of the carbon-dioxide concentration necessary to restrain the static electricity, and it is possible to reconcile the prevention of the gas bubble's influence with the restraint of the static electricity.

In summary, the carbon-dioxide concentration in the water supplied to the liquid film 4 ranges preferably from 0.02 ppm to 750 ppm, and more preferably from 0.06 ppm to 300 ppm. The equivalent condition is that the resistivity ranges preferably from 0.02 MΩ·cm to 10 MΩ·cm, and more preferably from 0.04 MΩ·cm to 5 MΩ·cm. This configuration prevents the influence of the gas bubbles to the exposure and restrains the static electricity on the substrate.